# CHARACTERIZING A FRESHWATER MUSSEL SHOAL IN THE WILLAMETTE RIVER IN EUGENE, OREGON, ~RM 180

*Margaritifera falcata (Western Pearlshells); C.A. Searles Mazzacano*

*Prepared for*: Travis Williams, Executive Director, Willamette Riverkeeper
*Prepared by:* Celeste A. Searles Mazzacano, Principal Scientist, CASM Environmental, LLC
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## Executive Summary

This project characterized a population of freshwater mussels in the Willamette River in a 300 m reach around RM180 in Eugene, OR. Surveys to assess population diversity, density, and viability were conducted from 31 July to 1 August 2018, using a systematic quantitative sampling design that combined semi-quantitative surveys across large proportions of the habitat with quantitative searches in a subset of the habitat (double sampling with excavation). Twenty bank-to-bank transects were set perpendicular to the direction of flow at 15 m (50 ft) intervals. In each transect, 0.25 $m^2$ quadrats were dropped at 15 m intervals and mussels visible on the surface were counted using a viewing scope or by snorkeling; every 3rd transect was double-sampled. A total of 158 quadrats were counted, 44 of which were double-sampled. The substrate throughout the reach was cobble and gravel intermixed with sand, overlaid in patches with sediment and macrophytes. Surveys found a total of 752 *Margaritifera falcata* (Western Pearlshell) and one *Gonidea angulata* (Western Ridgemussel); the invasive bivalve *Corbicula fluminea* (Asian Clam) was noted in 72% of the quadrats. Mussel abundance was concentrated in the downstream 170 m of the reach; *M. falcata* were found on both sides of the upper island, and the *G. angulata* was at the upstream end of the upper island close to the shore. Shell length of all mussels in double-sampled quadrats was measured as a surrogate for age. The *G. angulata* length was intermediate for this species, indicating a mature but not senescent adult. No juvenile (<30 mm) *M. falcata* were found, but four mussels close to juvenile size were seen (34.5 - 56.4 mm). Mean *M. falcata* length was 10.24 cm$\pm$1.31 (min = 3.45 cm; max = 12.47 cm), and >90% of excavated quadrats that contained live mussels included mussels smaller than 10.0 cm. Shell morphology and orientation in the substrate were typical for this species. Few dead mussels were found, and the ratio of live to dead was almost 20:1. The mean proportion of the population that was buried (32.3%) was greater than reported for *M. falcata* in other rivers, but similar to that seen for another large *M. falcata* population ~30 miles downstream (Norwood Island). The burial factor was determined to be 1.84. This was used as a correction factor in total counts, and an overall density of 28.0 mussels/$m^2$ was calculated for this reach. This *M. falcata* population is less dense than the one at Norwood Island, but the younger-shifted age distribution, smaller size classes, and lower mortality makes it viable at this point, and it may be an important source of reproductive replacements. However, only 12% of measured mussels were $\leq$90 mm, which raises concerns about the number of juveniles entering the system and their ability to settle and grow into reproducing adults. Surveys in spring and summer to find gravid females and broadcast glochidia masses could provide an indication of the population's reproductive activity. Because *Margaritifera* are so long-lived ($\geq$100 years), this and other extant populations in the Willamette should be re-surveyed every few years to assess changes in viability and potential responses to stressors and/or conservation efforts. The lone *G. angulata* is striking, as there are few recent records of this species from the Willamette River. The moderate shell length argues against it being the single remaining member of a larger population that senesced and died out. This individual could represent chance passage of an infested host fish, which depending on the species and distribution of *G. angulata* in other parts of the river may be an unusual occurrence. Timed searches to examine all the substrate in this reach along with intensive investigation of additional patches of the sand/gravel habitat preferred by *G. angulata* upstream and downstream of this region could reveal more individuals.

## Background

North America is a global hotspot for freshwater mussel diversity, with >300 known species (Graf & Cummings, 2007). The Pacific region is home to only a handful of these, but our low diversity is comprised of endemic species found nowhere else in North America, including the Western Pearlshell (*Margaritifera falcata*), Western Ridgemussel (*Gonidea angulata*), and several species of *Anodonta* (Floaters; *A. beringiana*, *A. californiensis/ nuttalliana* clade, and *A. oregonensis/kennerlyi* clade), all of which are thought to be more closely related to Eurasian or Asian species than to other North American mussels (Smith, 2001; Campbell et al., 2005; Chong et al., 2008; Haag, 2009; Lopes-Lima et a., 2017). All three genera are known to occur historically in the Willamette River, but a thorough survey of the entire river or basin has never been done, and historic and recent records are spotty and incomplete. In 2017, Willamette Riverkeeper conducted informal surveys across large reaches of the Willamette River to discover populations of mussels to be prioritized for more intensive surveys to determine diversity, density, age structure, and status. This project was undertaken to characterize a large population of freshwater mussels in the Willamette River around two small islands near Maury Jacobs Park in Eugene, Oregon.

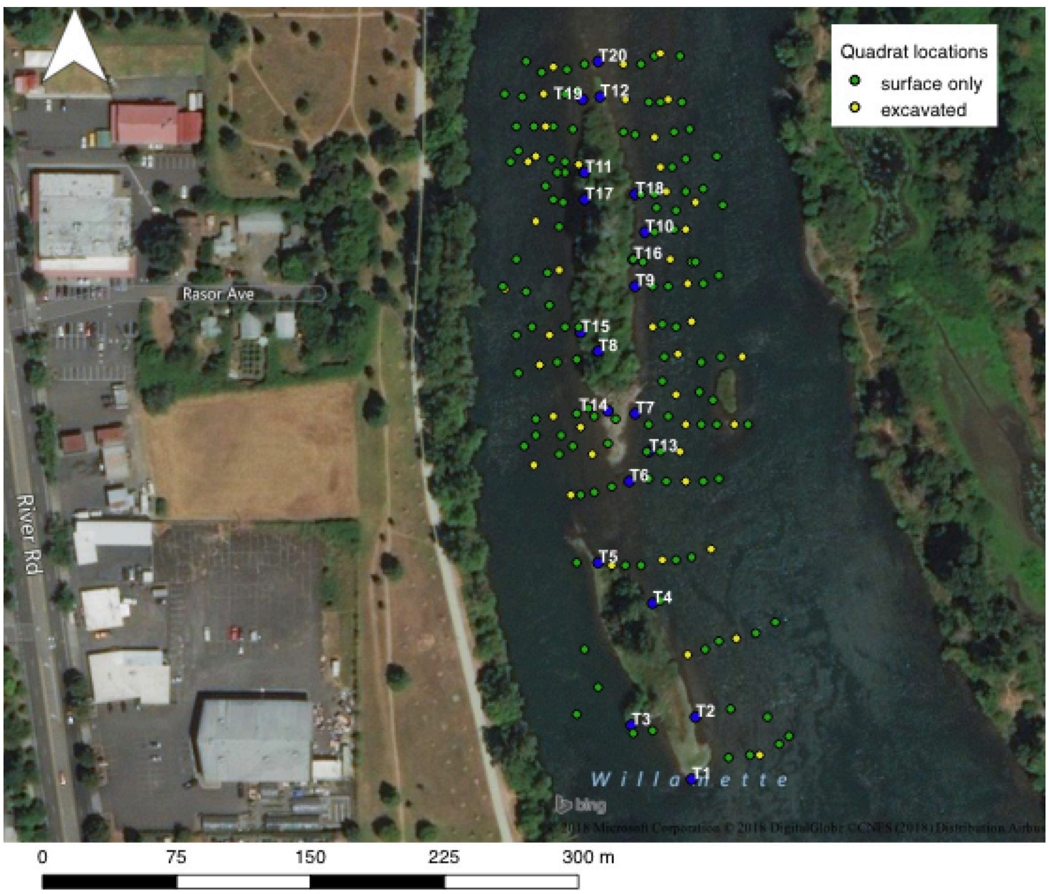
## Methods

Surveys were conducted from 31 July to 1 August 2018 by staff of CASM Environmental, Willamette Riverkeeper, and volunteers associated with Willamette Riverkeeper and the Pacific Northwest Native Freshwater Mussel Workgroup. The survey period was chosen to coincide with summertime base flow, as lower water levels increase visibility and ease of movement in the channel. A systematic quantitative sampling design based on established techniques was used (Miller & Payne 1993; Vaughn et al., 1997; Dunn, 2000; Strayer & Smith, 2003; Pooler and Smith, 2005; Stagliano, 2010), and combined semi-quantitative surveys across larger proportions of the habitat with quantitative searches in a subset of the habitat (i.e., double sampling with excavation). Survey transects encompassed a 44,400 $m^2$ reach (300 m long x 150 m bank-to-bank) in the Willamette River around RM 180, just downstream of Maury Jacobs Park in Eugene, OR. The reach contains two small islands that occupied about 500 $m^2$ of channel area. The substrate in the reach was cobble and gravel, intermixed with sand.

Bank-to-bank transects were set perpendicular to the direction of flow at intervals of about 15 m (50 ft), for a total of 20 transects in the reach (Figure 1). At each transect, coordinates of the starting point on the bank were recorded using a Garmin GPS unit, and a polypropylene rope knotted at 15 m (50 ft) intervals was paid out while surveyors moved in as nearly perpendicular a line as possible towards the opposite bank. At every knot on the rope, a 0.25 $m^2$ quadrat was dropped and the number of live and dead mussels visible at the surface of the substrate was recorded. Non-native Asian Clams (*Corbicula fluminea*), an invasive species found in Oregon since 1948 (Foster et al., 2017), were noted but *Corbicula* abundance was not recorded. Counts were done using Aquascopes in water less than ~1 m (3 ft) deep and by snorkeling and/or diving in deeper areas. Every 3rd quadrat in the transect was double-sampled, i.e., after the surface count was done, the substrate was excavated to a depth of 10-15 cm (3-5 in.) using hands and/or a small trowel. Excavated material was sieved though a 4 mm grid and all mussels in the sample material were counted. The shell length of each live mussel in the double-

sampled quadrats was measured to the nearest mm using vernier calipers, as a proxy for mussel age. Each mussel was then replaced in the substrate in its original orientation. The number of dead mussels was recorded but valves (shells) from dead mussels were not measured.

**Figure 1.** Location of survey transects and quadrats. Transect starts were located on the island shores (blue dots); surveys proceeded towards each bank in a line perpendicular to the river's flow. Green dots = quadrats where surface counts only were done; yellow dots = quadrats that were double-sampled.




Double-sampling allows the proportion of buried mussels and the size classes of all mussels to be determined in each excavated quadrat. In addition, because juvenile mussels (<30 mm long) are buried for the first few years of their lives, surface counts are biased towards larger, older individuals, and double-sampling ensures that young mussels in the population are not missed. If the reach width did not allow a full 150 m transect and/or if the depth increased to the point where excavation was not possible even with diving, then the 3rd, 6th, and final quadrats dropped were double sampled.

Mussel distribution is expected to be clumped and variable within a population (Downing & Downing, 1992), so it is necessary to count an appropriate number of quadrats to obtain a desired precision level. Sample size for a desired precision level can be calculated as ( [2 x SD] / [p x X] )$^2$, where X = population mean estimated from a pilot survey, SD = standard deviation of the mean, and p = the desired precision level (Dunn, 2000). Mean mussel numbers were not known at this site prior to the survey, so population means from a similar survey done in 2017 in the Willamette River at Norwood Island (RM 149) were used (Searles Mazzacano, 2017). Based on those numbers, the desired sample size to attain a 20% precision level at a 95% confidence interval in this survey was calculated to be ~140 quadrats. In addition, Smith et al. (2000) recommend a sample size of 100-200 quadrats for mussel populations $\geq 1/m^2$ to attain more precise density estimates. In actuality, a total of 158 quadrats were surveyed in this project, of which 44 (28%) were double-sampled.

Data analysis and graphing were done using the PAST3 software package (Hammer et al., 2001). Maps and area calculations were done using the QGIS software package (Quantum GIS Development Team, 2009).

## Results & Discussion

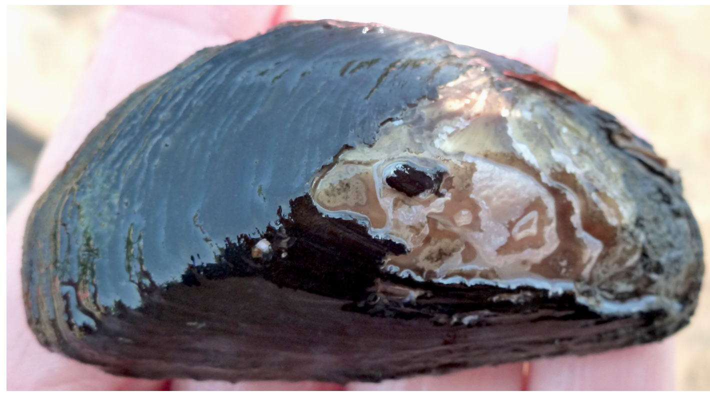
### MUSSEL DIVERSITY AND ABUNDANCE

A total of 752 live mussels and 39 dead mussels was counted among the 158 quadrats surveyed (i.e., quadrats in which surface counts only were done and those that were double-sampled with excavation). All native mussels were Western Pearlshell (*M. falcata*), with the exception of a single Western Ridgemussel (*Gonidea angulata*) found in quadrat #1 of transect 14, near the upstream end of the northern island (Figure 2). The discovery of *G. angulata* is significant; this species is currently rated Vulnerable by the International Union for the Conservation of Nature (IUCN Red List; see http://www.iucnredlist.org/details/173073/0), and there are few recent records (i.e., since 2000) of this species from the Willamette River. As the only known living taxon in a monospecific genus (Campbell et al., 2005; Lopes-Lima, 2017) with no close taxonomic relationship to other North American mussels, *G. angulata* is unique among our endemic western bivalve fauna. Non-native Asian clams (*Corbicula fluminea*) were also present throughout the reach and were found in 72% of the quadrats surveyed (Figure 2).

The number of mussels per quadrat in surface counts alone ranged from 0 to 35 (mean = $3.8 \pm 6.2$); when total counts from double-sampled quadrats are included, the number of mussels per quadrat ranged from 0 to 40 (mean = $4.8 \pm 7.6$) (Figure 3). In four of the double-sampled quadrats, surface counts alone found no live mussels, while excavation revealed anywhere from two to 13 live mussels. The shoal was concentrated in a ~170 m span encompassing the northern island, with the highest counts in the channel on the western side (Figure 3). The population was sparse in the upstream end of the reach; only two of the 24 quadrats surveyed around the southernmost island contained live mussels, with just a single individual in each. It was not possible to extend the survey transects to each opposite shore, as the water was too fast and deep for visual surveys or excavation via

skin-diving. However, mussels were visible in some of the deeper regions, and it is likely that this shoal extends to some degree deeper into the channel.

**Figure 2.** Mussel species in reach. Left = Western Pearlshell (*Margaritifera falcata*) anchored in the substrate, with an Asian Clam (*Corbicula fluminea*) lying on the surface at the lower right; Right = Western Ridgemussel (*Gonidea angulata*).



Mussels are primarily sessile creatures; the parasitic larvae (glochidia) can travel many miles attached to their host fish, but adults are limited to vertical burrowing and horizontal crawling. For this reason, mussels tend to be more abundant in areas of low shear strength and more stable habitat (Vannote & Minshall, 1982; Lazer & Madison, 1995; Strayer, 1999; Howard & Cuffey, 2003; Stone et al., 2004; May & Pryor, 2015), where juveniles can settle and grow without experiencing adverse effects from flow or other local environmental factors in the course of their long lives. *M. falcata* are often found in cobble/gravel substrates in runs, and can be especially abundant where large boulders stabilize interstitial gravels; *G. angulata* prefer stabilized sand and gravel bars in waters 1-3 m deep, but have also been found at depths of 4-8 m in some northern lakes (Vannote & Minshall, 1982; Howard, 2010; Stagliano, 2010; COSEWIC, 2010; Davis et al., 2013; Nield et al., 2014; Byron & Tupen, 2017).

The substrate in the survey reach was cobble and gravel intermixed with sand, overlaid in patches with soft sediment and plants, especially in the eastern channel (Figure 4). Substrate characteristics were similar throughout the reach, with an abundance of the cobble/gravel preferred by *M. falcata;* the absence of mussels from the upstream end of the reach and the lower abundances on the eastern side of the larger downstream island may thus reflect differences in long-term flow refugia. The lone *G. angulata* was in shallow water near the shoreline of the gravelly upstream end of the larger island; a dedicated survey of the entire shallow gravel bar between the two islands could reveal additional specimens, especially as this species is often found buried in the substrate with only its siphons exposed (Vannote & Minshall, 1982; Byron & Tupen, 2017) and may be more cryptic than *M. falcata*.

**Figure 3.** Number of live mussels in quadrats. Left = # of live mussels in surface counts only; Right = total # of live mussels (includes [surface+buried] in excavated quadrats). White = 0 mussels; pale yellow = 1-10 mussels; dark yellow = 11-20 mussels; orange = 21-30 mussels; red = 31-40 mussels. Dot size increases with each abundance class. Arrow indicates location of the single Western Ridgemussel (*G. angulata*) found.

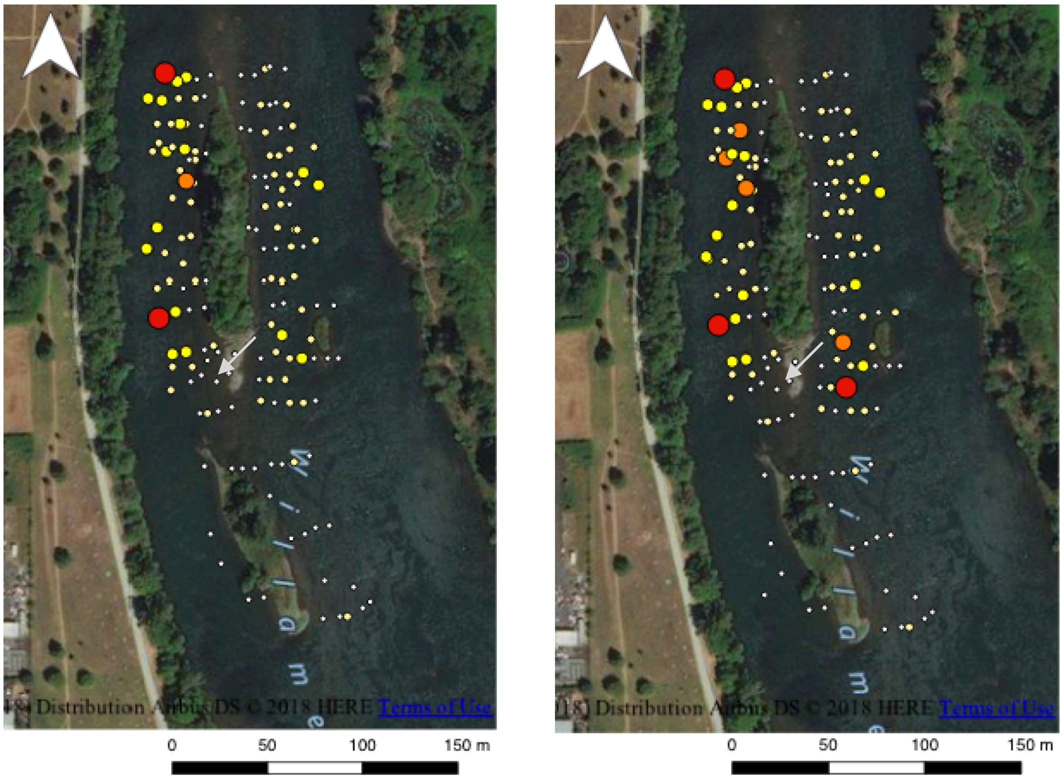
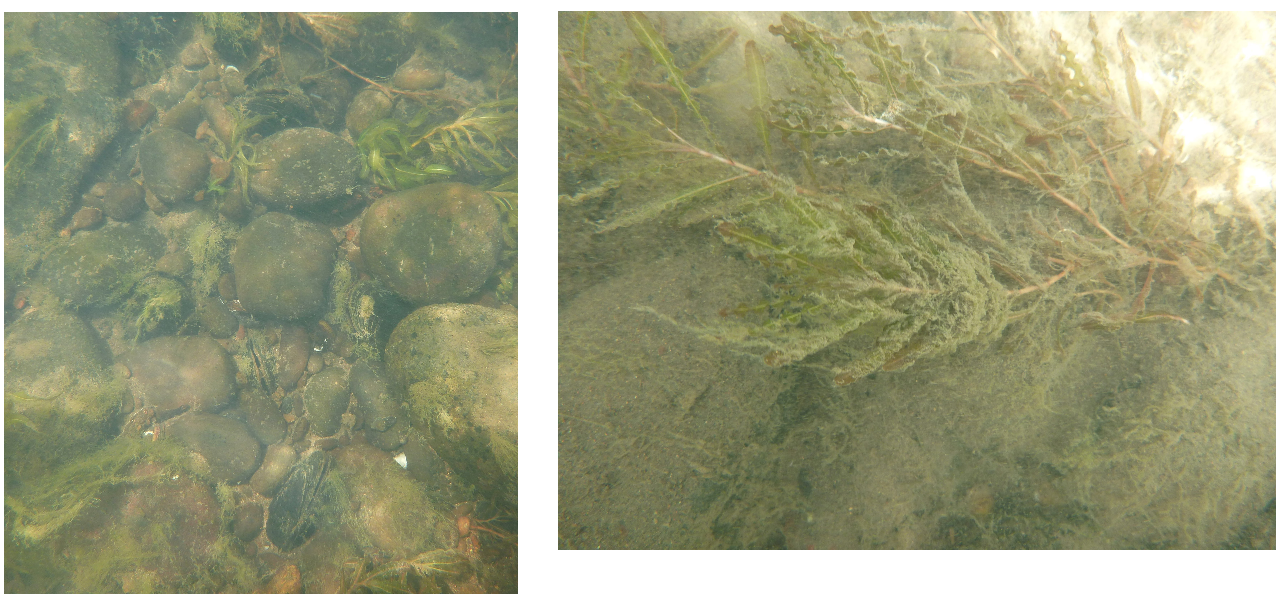


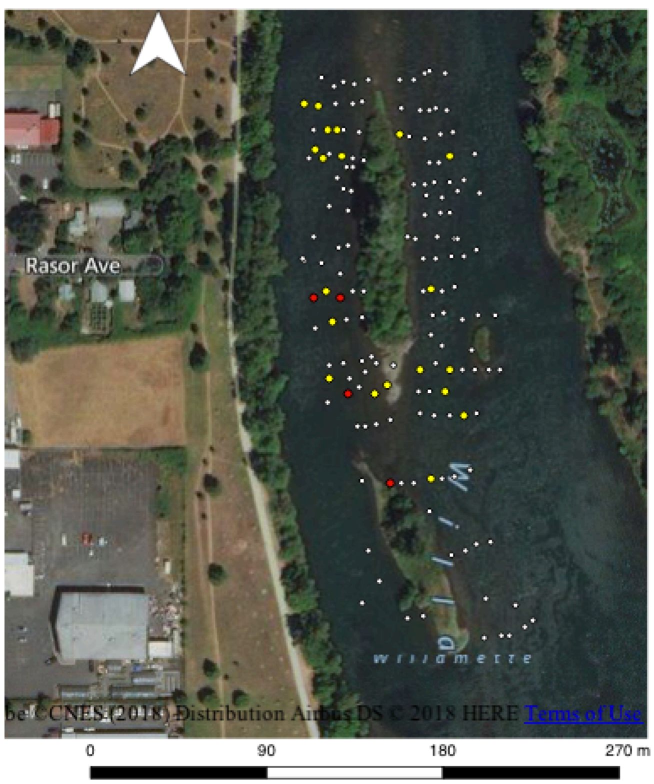

**Figure 4.** Substrate in survey reach. Left = several *M. falcata* embedded in interstitial gravel/sand in cobble substrate; Right = close-up of sediment and plants that coated cobble in patches throughout the reach.



## RELATIVE ABUNDANCE OF DEAD MUSSELS

Valves from dead mussels were seen in only 15% of the 158 quadrats surveyed, and were present in low abundances (mean = 1.6±1.0). Live mussels were found at the surface and/or buried in more than half (55%) of the quadrats surveyed, and most of these (78%) did not contain any dead mussels. Forty-one percent of the quadrats searched did not contain either live or dead mussels, and 4% of the quadrats had only dead mussels. The ratio of live to dead mussels in quadrats with both ranged from 1:1 to 40:1 (mean = 12.3±10.4), and the total ratio of live to dead mussels in the survey was 19.3. The spatial pattern of quadrats with dead mussels was similar to that seen for live, with most concentrated around the larger island, especially in the western channel (Figure 5).

**Figure 5.** Distribution of dead mussels in survey quadrats. The number of dead mussels did not exceed four in any quadrat. White = 0 dead mussels; yellow = 1 or 2 dead mussels; red = 3 or 4 dead mussels.




Mussel mortality occurs due to a variety of factors including old age, disease, predation, flow disturbances (i.e., from de-watering and stranding or being scoured out by high flows), and adverse environmental impacts (i.e., low food quality or availability, chemical contaminants, low dissolved or interstitial oxygen levels, changes in pH, excess sedimentation), any of which may be operating in combination at a given site or time. Most healthy mussel populations are considered to be characterized by high adult survival, with mortality primarily due to old age. No

established “natural” level of mortality in *Margaritifera* populations has been determined, and 10-year mortality rates in European populations of *M. margaritifera* were found to vary from <10% to as much as 80% (Bauer, 1987; Skinner et al., 2003). Low adult mortality of this extremely long-lived species is thought to compensate for high rates of glochidial and juvenile failure, and surveys of other large populations of western *M. falcata* have found anywhere from few to no dead mussels (Helmstetler & Cowles, 2008), to nine times as many dead shells as live mussels (Hastie & Toy, 2008). The ratio of live to dead mussels in this population is over five times higher than that of the Norwood Island population in the Willamette River (see “Comparison with Norwood Island mussel population” below). Several weathered and fresh valves were found on the shore of the smaller upstream island and many showed marks of mammalian predator attacks, including parallel scratches on the periostracum and jagged holes in the valve (C.A. Searles Mazzacano, pers. obs.). It is likely that observed mortality at this site is due primarily to death of older adults and predation, but in the absence of an established expected population mortality rate, additional factors cannot be ruled out.

## SURFACE DETECTION OF MUSSELS

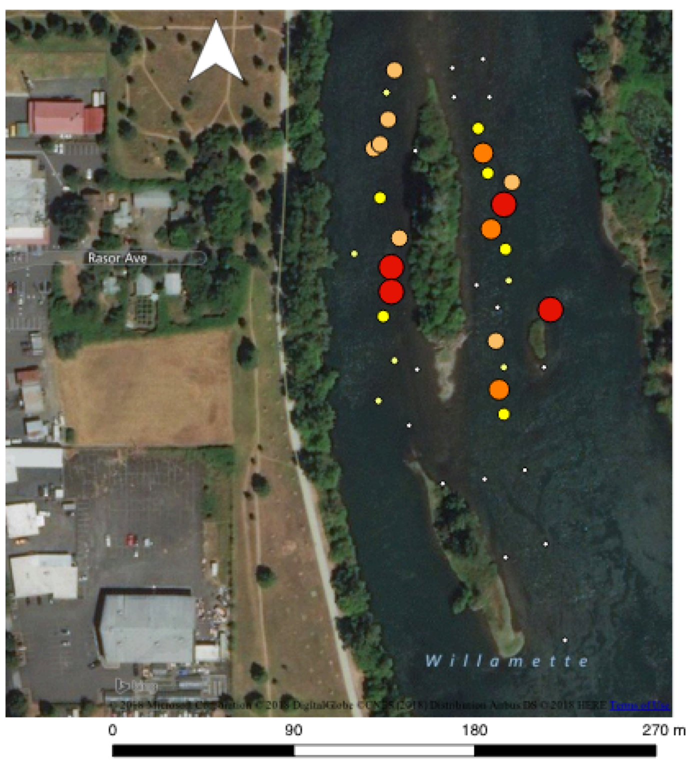
Double-sampling is done to obtain density estimates closer to the true population density. Smith et al. (2000) suggest that to minimize variance, 25% of quadrats should be excavated if >60% of the mussels are likely to be detected at the surface, and 33% of quadrats should be excavated if 50% of the mussels are detectable at the surface. In a previous survey of a shoal around Norwood Island (Searles Mazzacano, 2017), 65% of all live mussels in excavated quadrats were detected at the surface. Because that substrate was rather atypical for *M. falcata*, with more sand and less cobble than is usually preferred by this species, it was anticipated that the proportion buried in this survey would likely not exceed that at Norwood. The sample design therefore called for 30% of all quadrats surveyed to be double-sampled. Depth and current in some places made excavation impossible, but ultimately 28% (44 quadrats) of the total quadrats surveyed were excavated, which is in the range recommended by Smith et al. (2000) for the degree of surface detection observed.

Fifty-four percent of the mussels counted among all double-sampled quadrats were detected at the surface. The proportion of mussels that were buried in each double-sampled quadrat ranged from 0-100%, and the mean proportion buried (32.3%±33.8%) was very similar to the mean proportion buried in the Norwood Island *M. falcata* population (32.9% ± 26.1). There was no strong spatial pattern to the degree of burial (Figure 6), although the western channel around the larger island had more quadrats in which 40-60% of the total mussels counted were buried, while the eastern channel had a greater number of quadrats in which 60-80% of the mussels were buried.

Many western mussel studies do not include excavation, and those that do may not report the proportion buried, so it is difficult to know what is a “normal” degree of burial for *M. falcata*, and how much that differs across watersheds. Studies of other *M. falcata* populations have found much smaller proportions buried. Howard & Cuffey (2003; 2006) found less than 0.5% of a population in the South Fork Eel River system buried; however,

most mussels found in that survey were in deep pools, which likely had greater substrate stability and less flow variability than the pearlshells in this study location. Byron & Tupen (2017) reported that *G. angulata* in several reaches of the Klamath River were “mostly to totally buried" but this appeared to refer more to the depth of the shell than to the proportion of the population. Historic flows in the Willamette River have been altered by dams, dredging, and flood control projects on the mainstem and its tributaries, and the river flow today is highly regulated; a greater degree of burial may be a way of coping with unpredictable flows.

**Figure 6.** Proportion of total live mussels found buried in the substrate in excavated quadrats. White = 0 live mussels buried; pale yellow = 1-20% of total mussels buried; dark yellow = 20-40% buried; pale orange = 40-60% buried; dark orange = 60-80% buried; red = 80-100% buried. Dot size increases with abundance class. Note that not all excavated quadrats appear here as some contained no live mussels.




## MUSSEL DENSITY

Excavating quadrats enables the proportion of mussels buried in the substrate to be determined; this value is then used as a correction factor when calculating population density. Surface counts found a total of 601 live mussels in 158 quadrats; in the subset of 44 excavated quadrats, 178 live mussels were visible at the surface and an

additional 150 were buried. The relationship between the true number of mussels in a quadrat to those visible at the surface (burial factor) is calculated as [#surface + #buried]/#surface (Strayer & Smith, 2003); for these surveys, this factor equals 1.84. Based on this burial factor, the number of mussels in all quadrats is 1.84 x 601 = 1,106. The 158 quadrats surveyed covered a total area of 39.5 $m^2$, which corresponds to a mussel density of 28/$m^2$.

Reported densities of *M. falcata* beds vary widely from stream to stream. O'Brien et al. (2013) designated beds in the Middle Fork John Day in Oregon as 'dense' if they contained >5 mussels/$m^2$, and Stagliano (2010) used densities of 0.5-1.0/$m^2$ as indicators of viable populations. Densities in this range have been reported for *M. falcata* in Washington rivers such as the Elwha River (2.8-11/$m^2$; Cole, 2010), Cedar Creek (mean density 2.3/$m^2$; Stone et al., 2004), and Clearwater River (8.6-21.4/$m^2$; Helmstettler & Cowles, 2008). During a die-off in Battle and Bear Creeks in Washington, Hastie & Toy (2008) found high initial *M. falcata* densities (80.8/$m^2$ and 56/$m^2$, respectively) in 1995, which decreased to 13.4/$m^2$ and 6.9/$m^2$ by 2006, and May & Pryor (2015) found *M. falcata* shoals as dense as 468/$m^2$ in the Trinity River in California. The mean mussel density in this reach, while not outstanding, thus lies within the range reported for *M. falcata* in several other western streams.

## POPULATION AGE STRUCTURE & STATUS

Mussel shell length is used as a proxy for age to assess population structure. The shell of the single *G. angulata* found was 6.19 cm long. This species attains lengths up to 12.5 cm (5 in.) in its 30-50 year lifespan (COSEWIC, 2010; Mageroy, 2015), and while a specific age cannot be assigned to an individual based solely on shell length, *G. angulata* specimens from the Salmon River in Idaho that ranged from 5.9 to 10.4 cm long were considered to be 10-22 years old (Vannote & Minshall, 1982). Although growth rates and maximum shell lengths within a species can differ between waterbodies and watersheds and are affected annually by stream discharge and other environmental factors (reviewed in Haag, 2012), this suggests the individual in this study was a mature but not senescent adult.

Shell lengths of all live *M. falcata* in excavated quadrats ranged from 3.45 to 12.47 cm (mean = 10.24$\pm$1.31), and 38.7% of all mussels were in the 10.01-11.00 cm size class (Figure 7). Size ranges given for juvenile *Margaritifera* vary from less than 50 mm (Howard, 2008) to less than 30 mm (Toy, 1998; Stagliano, 2010). No mussels in this population measured less than 3.0 cm, but the smallest (3.45 cm) was near the lower range for juvenile size, and 33% of measured mussels were $\leq$ 9.99 cm long. Over 90% of excavated quadrats that contained any live mussels included mussels <10.0 cm, and 15.5%-100% of the total mussel abundance in individual quadrats consisted of these smaller/younger mussels. Apart from the fact that the majority of mussels in the reach were concentrated around the larger island, there was no apparent spatial bias to quadrats with higher proportions of smaller mussels, as they were distributed on both sides of the channel around the upper island (Figure 8).

**Figure 7.** Proportion of *M. falcata* (Western Pearlshell) population in different size classes. Shell lengths were measured only in double-sampled quadrats.

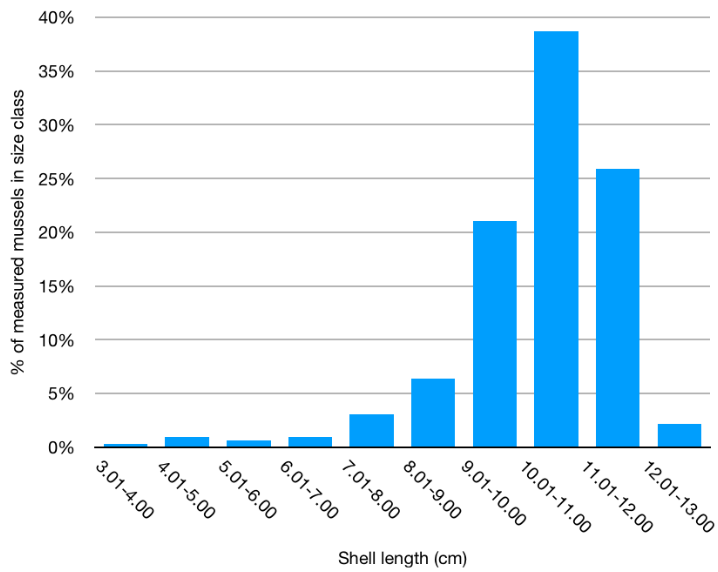



**Figure 8.** Proportion of total live *M. falcata* (Western Pearlshell) in excavated quadrats that were <10.0 cm in length. White = 0; yellow = 1-25%. light orange = 26-50%; dark orange = 51-75%; red = 76-100%. Dot size increases with each class.

Adults in the genus *Margaritifera* reach lengths of 7.7-15.8 cm (Bauer, 1992; Hastie et al., 2000; Skinner et al., 2003), and individuals are considered to be reproductively active by the time they attain at least 4.0 cm in length (Toy, 1998; Allard et al., 2017). *M. falcata* in this study skewed towards larger/older mussels, although most measured mussels were in the middle of this range (i.e., 10-11 cm), and none were longer than 12.47 cm. Viability of mussel populations is assessed based on both population density and age structure; ideally, a viable population has both juveniles (indicating active recruitment) and older adults (indicating habitat and environmental conditions that support adult longevity). Stagliano (2010) used the following criteria to rank the viability of *M. falcata* populations in Montana streams:

- excellent viability: density >1/$m^2$ of stream, beds with >50 individuals, wide range of size classes, mussels <30 mm (juveniles) present;
- good viability: densities >0.5/$m^2$ of stream, beds with >25-50 individuals, wide range of size classes, mussels <30 mm present;
- fair population, not viable: low densities >0.1/$m^2$ of stream, beds with <25 individuals, limited size classes, no juveniles;
- not viable: very low densities, single live individual in large size class; and
- verified extant: recent shell records but no live mussels.

Based on the above criteria, this *M. falcata* population is best characterized as having good viability. Although the densities are above those specified for excellent viability and there are 10 different size classes, no mussels ≤30 mm were found and only 12% of the measured population was ≤90 mm. The intermediate length of most of the adult mussels (9.0-12.0 cm) suggests that the majority of the population is reproductively active. Moreover, the observed density (28 mussels/$m^2$) in a relatively short reach should put males and females in close enough proximity that sperm broadcast by males during spawning can be taken up and used by females to fertilize their eggs; previous studies have indicated that for some species, local densities of at least 10 mussels/$m^2$ are needed to ensure successful reproduction (Downing et al., 1993). Thus, this shoal could be an important source of reproductive replacements for other reaches of the river, provided that appropriate host fish species are present when glochidia are broadcast. Host fish for *M. falcata* are salmonids including chinook, rainbow trout, coho, cutthroat trout, and steelhead (Meyers & Milleman, 1977; Karna & Millemann 1978; Stock, 1996). The length and timing of *M. falcata* glochidia release is not fully characterized (Howard & Cuffey, 2006); in the Middle Fork John Day River in Oregon, gravid *M. falcata* were not seen later than early May, suggesting that their reproductive cycle was completed by summer (O'Brien et al., 2013). The timing of glochidia release by females is thought to be affected by water temperature and is likely to vary in different habitats; springtime surveys to observe gravid mussels and/or released glochidia masses would be required to determine the timing in this reach.

Recruitment success of new juveniles is affected by presence and seasonality of host fish carrying glochidia, stream hydrology, and substrate composition and stability; without additional studies it is not possible to state whether the low proportions of the smallest size classes in this population are due to low numbers of glochidia

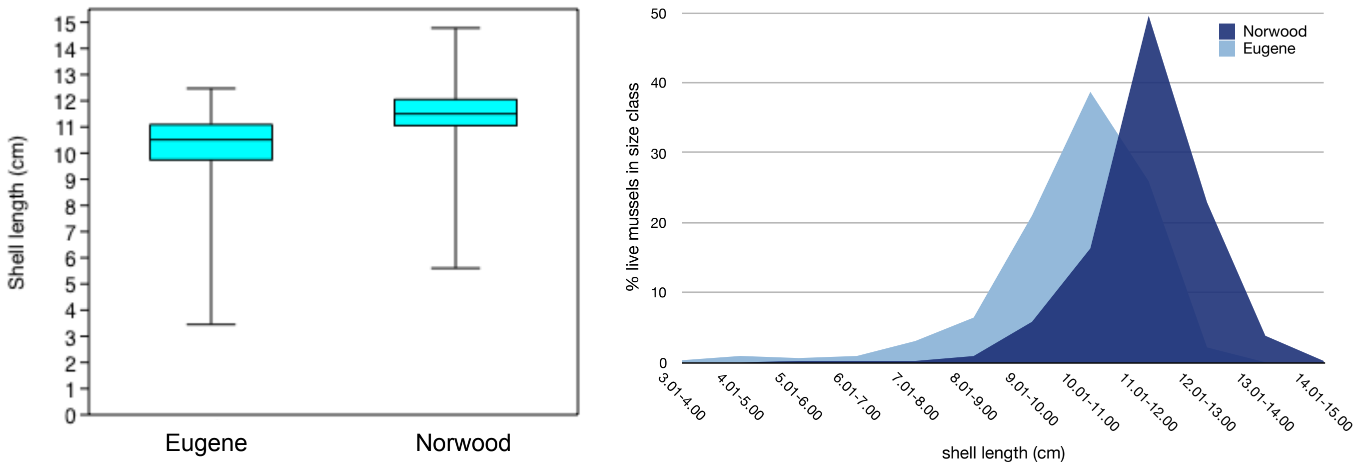
(i.e., few infested host fish moving through the system) or high levels of juvenile failure (i.e., juveniles dropping off host fish in areas where they are unable to settle and survive to adulthood). *M. falcata* recruitment success was related to discharge in California rivers, with more successful recruitment during low-discharge years compared to high-discharge years (Howard & Cuffey 2006), so recruitment success and juvenile survival may vary from year to year with climate and flow.

### Comparison with Norwood Island mussel population

A large mussel shoal in the backchannel at Norwood Island in the Willamette (RM 148-149) was recently characterized in a similar study (Searles Mazzacano, 2017). The Norwood population also consisted primarily of *M. falcata*, but six floaters (*Anodonta oregonensis/kennerlyi*) were found as well. Asian clam was present at both sites, but with a higher relative abundance at Eugene (found in 72% of quadrats vs. 13% at Norwood). The habitat at Norwood had more sand and less cobble than the reach at Eugene, and many *M. falcata* had unusual morphologies, with the shells of some exhibiting extensive, deeply eroded patches and grooves and an exaggerated concavity at the ventral edge; a similar exaggeration of the ventral curve has been reported for *M. falcata* in other rivers (Cole, 2010), but no causative agent as identified. Many live *M. falcata* were also observed lying on the substrate surface in the Norwood channel. The mussels in the reach at Eugene exhibited typical shell morphology, less extensive erosion of the valves, and the majority were embedded in the substrate. Both populations had a relatively large proportion of mussels that were buried in the substrate and detectable only after excavation, although the burial factor was higher at Eugene (1.84) than at Norwood (1.54).

*M. falcata* were more dense at Norwood Island (46.3/$m^2$) than at Eugene (28/$m^2$), but the ratio of live to dead mussels was over five times higher at Eugene. The greater relative abundance of dead mussels in the Norwood channel could be due in part to location, as dead mussels can be washed in from further upstream and drop out in the slower areas of the backchannel. However, a higher proportion of older and senescent mussels could also be a contributing factor at Norwood. Both populations had mussels in 10 different size classes and both skewed towards older adults (Figure 9), but the Norwood mussels were larger overall (mean length 11.48 cm $\pm$ 0.95 vs. 10.24 cm $\pm$1.31 at Eugene), had a greater proportion of mussels >10.0 cm (92.8% vs. 66.7% in the Eugene population), and lacked the two smallest size classes found in the Eugene population. A few mussels in the Eugene population were close to juvenile size (Figure 9), and over 90% of the excavated quadrats contained at least one mussel <10.0 cm, as opposed to only 40% in the Norwood population.

**Figure 9.** Age structure of *M. falcata* populations at Eugene and Norwood Island. Left = Shell lengths of all live *M. falcata* (Western Pearlshell) in excavated quadrats. Horizontal line in each box indicates median value; filled boxes show interquartile ranges; whiskers depict data range. Right = proportion of measured mussels in each size class.




## Conclusions

This 300 m reach of the Willamette River is home to a moderately dense population (28 mussels/m$^2$) of Western Pearlshell mussels (*M. falcata*), concentrated in a 170 m span encompassing the northernmost of two small islands in the reach. This population is less dense than the one previously characterized at Norwood Island, but the younger-shifted age distribution, smaller size classes, and lower mortality makes it viable at this point. However, only four of the 328 mussels found in double-sampled quadrats were within the size range given for juvenile mussels (30-50 mm), and no mussels smaller than 30 mm were seen. This raises concerns about the number of juveniles entering the system and their ability to successfully settle and grow into reproducing adults. With only a single set of observations, it is not possible at this point to know whether this population is declining, static, or increasing, and re-surveying within the next 5 years would be required to reveal the trend. For example, Stagliano (2015) found that the proportion of *M. falcata* populations in Montana rivers considered to be viable (excellent, good, or fair) based on survey data collected prior to 2010 had decreased by 8-18% when sites were re-surveyed in 2014, and Hastie and Toy (2008) found that the density of large *M. falcata* populations in two Washington streams declined by more than 75% in a 10-year period.

The abundance of adult mussels and low proportion of valves from dead mussels indicate that substrate, flow, and nutrients are sufficient for growth and longevity. This large shoal could be an important source of reproductive replacements for the system; examining adults in spring to find gravid females (indicated by swollen gill chambers) and surveying the substrate for broadcast masses of glochidia in spring and summer could provide an indication of the population's reproductive activity. The lower numbers of juvenile and very young mussels observed could be due to a variety of factors, including low numbers of host fish infected with mature glochidia passing through the reach and/or inability of very young mussels to persist to adulthood. The substrate in the reach is the cobble/gravel type preferred by *M. falcata*, but juveniles may require different microhabitat, and the widespread and abundant

Asian clams observed in the reach may be an additional stressor impacting resource availability for juveniles (Sousa et al., 2008; Pigneur et al., 2014).

The presence of a lone Western Ridgemussel is striking and raises additional questions about the distribution of this species in the Willamette River, especially as *G. angulata* is understudied even among our western Unionoida. The moderate shell length suggests it is not an extremely old adult, which argues against it being the single remaining member of a larger population that senesced and died out. While *G. angulata* and *M. falcata* are known to co-occur (Howard, 2010; Davis et al., 2013), their habitat preferences differ, with *G. angulata* preferring stabilized sand/gravel and river banks (Vannote & Minshall, 1982; Howard, 2010; Davis et al., 2013). Thus, a single *G. angulata* in the midst of hundreds of *M. falcata* may mean that the habitat in the 170 m reach where most mussels were concentrated is not ideal for *Gonidea*. Timed searches to examine all of the substrate in this reach along with intensive investigation of additional patches of sand/gravel habitat upstream and downstream of this reach could reveal more *G. angulata*. It is also possible that this individual represents the chance passage of an infested host fish, which, depending on the species and the distribution of *G. angulata* in other parts of the river, may be an unusual occurrence. Host fish species for glochidia of *G. angulata* have yet to be determined, but may include sculpin, hardhead, Tule perch, Longnose dace, and Northern Pikeminnow (Spring River, 2007; O'Brien et al., 2013; Mageroy, 2015).

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